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20050704

**EFFECTS OF GRAIN LEGUMES IN NO-TILL CROPPING
SYSTEMS ON SOIL QUALITY AND NITROUS OXIDE
EMISSIONS**

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FINAL REPORT
Saskatchewan Agriculture Development Fund
Project #20050704

Project Title: Effects of Grain Legumes in No-Till Cropping Systems on Soil Quality and Nitrous Oxide Emissions.

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Time Frame for Study: Three years (April 1st, 2005 to March 31st, 2008)

Executive Summary:

The objectives of this project were to determine the effect of grain legumes and their frequency in rotation on nitrous oxide emissions, soil bio-diversity, carbon and nitrogen sequestration and nutrient cycling in no-till cropping systems. This research will be carried out on an ongoing 10-year Agriculture and Agri-Food Canada Field Pea Management Study (now 13 years), located in the thin black soil zone at Indian Head, SK. The field study consists of different frequencies of field pea in a wheat-based rotation. There was interest in answering a number of questions.

- a. Can increasing the frequency of grain legumes in a rotation increase the rate of carbon sequestration?
- b. What is the impact of increasing the frequency of grain legumes on soil quality in terms of organic carbon, nitrogen fractions, nitrogen cycling and nitrogen releasing power of the soil?
- c. What is the impact on the soil microbial diversity?
- d. What is the impact on nitrous oxide emissions?
- e. How do grain legumes with no added fertilizer N compare to spring wheat with added fertilizer N for greenhouse gas emissions?

Section 1: The effects of crop and crop rotations on soil microbial biomass, diversity, enzyme activity and populations of rhizobia.

Although there were exceptions, microbial biomass, β -glucosidase enzyme activity and bacterial diversity tended to decrease with increasing frequency of pea in rotations. Crop effects sometimes explained the results, e.g., enzyme activity was greater in wheat rhizosphere than in pea rhizosphere, and greater in the rhizosphere of wheat grown on wheat stubble than in wheat on pea stubble. However, enzyme activity in the rhizosphere tended to be greater where N had been applied than where it had not been applied. Therefore, N fertilization probably explains the rotation and crop effects, even though N effects were not always significant, because wheat received up to 80 kg N ha^{-1} and pea only up to 40 kg N ha^{-1} . Nitrogen fertilizer probably had the indirect effects of improving crop growth resulting in greater root exudation in the rhizosphere. While enzyme activities tended to decrease with increasing pea frequency in the rhizosphere, the reverse tended to be true in bulk soil. The difference is probably related to root exudation effects in the rhizosphere and crop residue effects (pea residues increasing enzyme activity) in bulk soil. Therefore, crop rotation effects on soil microbial dynamics depend on the effects of the current crop and its management (e.g., fertilizer application) on root exudation in the rhizosphere, and the effect of decomposing residues of the preceding crop in bulk soil.

Section 2: The effects of crop and crop rotation on soil bulk density, soil organic carbon and nitrogen.

A rotation effect was observed for the 0-3" soil layer from the 1994 soil samples before the study started reflecting effects of spatial variability. No differences were observed in 2005 due to rotation. An effect looking at the increase in carbon due to rotation was observed for the 0-3" soil layer. This is essentially measuring carbon sequestration. No important differences were observed for the 3-6" soil layer. The carbon sequestered per year after 10 years for the 0-6" soil layer in rotation 1 was $275 \text{ kg C ha}^{-1} \text{ year}^{-1}$, rotation 2 sequestered $472 \text{ kg C ha}^{-1} \text{ year}^{-1}$ and rotation 3, $361 \text{ kg C ha}^{-1} \text{ year}^{-1}$. One could argue that the amount of carbon sequestered with continuous grain legumes was the largest supporting the notion that increasing the frequency of grain legumes in the rotation accelerates carbon sequestration. However rotation 3 had more carbon sequestered than rotation 1 and rotation 3 has field pea every three years as opposed to every second year in rotation 2. It should be noted that although Rotation 2 (Continuous-Pea) yielded less, on average, it tended to sequester as much or more carbon than the other pea phases of the rotations studied.

Section 3: The effects of crop and crop rotation on nitrous oxide emissions.

Pea phases tend to have lower emissions during the growing season than wheat phases. Fertilizer-induced N_2O emissions may be higher in the presence of pea residues, but this is more than offset by lower emissions during the field pea phase. At this site, applying fertilizer N increased the potential for N_2O loss, particularly when combined with pea residues, but that potential was only strongly expressed when soil-water regimes were favorable for N_2O production (higher than average

rainfall). On average, over this three-year study increasing the frequency of field pea in rotation with spring wheat tended to decrease the loss of soil-emitted N_2O .

Section 4: The effects of crop and crop rotation on nutrient cycling.

Grain legume residues have higher nitrogen contents than cereals grown at recommended rates of nitrogen. It is hypothesized that residues with higher nitrogen contents may cycle faster or get more readily incorporated into the soil organic matter fraction. An attempt was made to determine if nutrient cycling is accelerated when the frequency of field pea increases in a cropping system by making direct in-situ measurements in the soil using PRS™ resin probes over three consecutive 14 day periods. The nutrients of interest were ammonium, nitrate, the sum of ammonium and nitrate (Total N), sulfur, potassium and phosphorus.

The largest effect with respect to N release was observed for ammonium-N after 14 days. The pea stubble was releasing more ammonium than wheat stubble in Pea-W (Rot 1) and Pea-W-W (Rot 3) rotations. However, the Cont-Pea (Rot 2) released the least amount of ammonium when compared to the Pea-W and Pea-W-W rotations. After 28 and 42 days, the Cont-Pea rotation was still releasing the least amount of ammonium-N.

With nitrate-N, differences were only apparent after 42 days. This is to be expected given that the mineralization of N from organic matter starts with the release of N in the form of ammonium followed by the nitrification process which produces nitrate-N. The field pea phase in the Cont-Pea (Rot 2) was releasing more nitrogen than the pea phase in Pea-W-W (Rot 3). Overall, the Cont-Pea (Rot 2) released more nitrogen than Pea-W. There was no statistical difference between Cont-Pea and Pea-W-W even though the release was higher for Cont-Pea.

With phosphorus, differences were observed between Pea-W (Rot 1) and Pea-W-W (Rot 3) on all three sampling dates. The pea stubble in Rotation 1 (Pea-W) was releasing more P than the combination of wheat on wheat or wheat on pea stubble in Pea-W-W (Rot 3). However, close examination of the results shows that lower values were observed for wheat on pea stubble than wheat on wheat stubble in Pea-W-W (Rot 3).

With potassium, Cont-Pea (Rot 2) released the least amount of K on all three sampling dates. The pea phase of Cont-Pea (Rot 2) also released less K than the pea phase of Pea-W (Rot 1) and Pea-W-W (Rot 3).

With sulfur, the only effect observed was with the use of starter N during the pea phase of Pea-W (Rot 1) and Cont-Pea (Rot 2). As starter N increased, the amount of sulfur released decreased linearly with N rate. This was consistent for both rotations and on all three sampling dates.

Based on the results collected, rotations and specifically pea had an effect on the release of the macro-nutrients, nitrogen, phosphorus, potassium and sulfur

Project Summary

Background:

The scientific evidence supports the concept that soils in Western Canada can sequester carbon dioxide from the air into soil organic matter. The extent of the sequestration is determined by the tillage and cropping system used. Nitrogen fertilizer represents a very important input in crop production because of its direct effect on crop growth which in turn contributes to higher fixation of carbon dioxide. N fertilizer use in crop production contribute to nitrous oxide emissions (N_2O). Also, the substantial energy required to manufacture N fertilizers further contributes to greenhouse gas emissions. However, the results to date indicate that N_2O and CO_2 emissions from manufacturing and N_2O emissions from agricultural use are more than offset by carbon sequestration.

There is indirect evidence to indicate that increasing the frequency of grain legumes in a rotation can accelerate C sequestration but the concept needs to be verified. Also, it is speculated that the lower C/N ration of grain legumes may result in the more rapid cycling of N which could contribute to N_2O emissions. The relative effects of inorganic fertilizers vs increasing grain legumes in a cropping system need to be quantified with regards to soil quality and N_2O emissions. If the results favor increasing the frequency of grain legumes, then the opportunity exists to increase the frequency of grain legumes in the cropping system to reduce N fertilizer use and at the same time reduce the potential for N_2O emissions occurring from inorganic fertilizer use. Consideration could then be given to growing grain legumes with high starch content for the ethanol industry increasing the ratio of energy output to energy input because of a reduced need for inorganic nitrogen.

A Field Pea Management Study (FPMS) initiated 10 years ago at the Indian Head Research Farm offers a unique opportunity to test this concept.

Objectives

The objective of this project was to determine the effect of grain legumes and their frequency in rotation on nitrous oxide emissions, soil bio-diversity, carbon and nitrogen sequestration and nutrient cycling in no-till cropping systems.

Activities

N_2O emissions will be measured on a study established in 1995 at the Indian Head Research Farm consisting of different frequencies of field pea in rotation under a no-till system. Rotation 1 is wheat-pea, Rotation 2 is continuous pea and Rotation 3 is wheat-wheat-pea. Each phase of these rotations will be measured weekly from spring soil thaw to fall freeze-up with twice weekly measurements from seeding to harvest.

Soil samples were archived in the fall of 1994 prior to the start of the study and these soil samples will serve as the benchmark for determining the improvements in soil quality after 10 or more years. Numerous aspects of soil quality will be measured as well as various aspects of soil microbiology. AAFC will take the responsibility of doing the soil quality analyses.

Although only one site is involved, in order to do a proper evaluation of the questions of interest, you require a site that has the proper management and longevity. The Indian Head

Research Farm has a study site with the required treatments with at least 10 years of history. It should also be noted that the Indian Head Research Farm is located in the thin-black soil zone and this soil zone represents about 30% of the cultivated acres on the prairies and also has a large number of acres growing grain legumes. The data will also provide useful information to producers doing a lentil-durum or field pea-durum rotation in the drier areas of the prairies.

Description of Study

Materials and Methods

Section 1: The effects of crop and crop rotations on soil microbial biomass, diversity, enzyme activity and populations of rhizobia.

Bulk soil (0-3") and rhizosphere samples were collected at the flag-leaf stage of wheat and the flowering stage of peas to measure soil microbial biomass and diversity of bacteria. Soil microbial biomass was measured using the substrate-induced respiration (SIR) method (Lupwayi et al. 1999. Can J. Soil Sci. 79:273-280). Bacterial functional diversity was evaluated using the Biolog™ method (Lupwayi et al. 2001. Appl. Soil Ecol. 16:251-261), which tests the ability of a microbial community to utilize different C substrates.

Soil samples (0-6") were also collected on September 19, 2005 to enumerate pea rhizobia using the most-probable-number (MPN) plant-infection method (Rice and Olsen 1993. Soil Sampling and Methods of Analysis. M.R. Carter, Ed. pp 303-317).

Section 2: The effects of crop and crop rotation on soil bulk density, soil organic carbon and nitrogen.

We took two samples per plot for each combination of treatment and replicate and bulked the samples by depth. The depth increments used were 0-3" (0-7.62 cm) and 3-6" (7.62-15.24 cm). The diameter of the core used was 65.26 mm giving an area of 33.449 cm². The volume of the core was 254.88 cm³. At each sampling point, we removed the crop residues at the soil surface so as to not include them in the samples. The samples were taken on May 30th, 2005.

Upon collection, the soil samples were dried at 60°C for a minimum of 48 hours. The samples were then weighed and ground. The dry weight was used to calculate bulk density of the soil so that the organic carbon of the soil and residues could be expressed on a mass basis.

Total carbon and total nitrogen for the soil and crop residues were determined using a NA1500 NCS Analyzer, supplied by Carlo Erba Instruments, using the manufacturers suggested operational parameters and protocols. Organic carbon is determined on the same equipment, using a new method for the automatic and selective determination of total organic carbon in sediments, soils, compost, particles in air, etc. by Marco Baccanti and Bruno Colombo (Carlo

Erba Instruments, Rodano (Milano), Italy). This method involves a pre-treatment of the sample with HCl in a silver capsule. The carbonates react to CO₂, while the soluble organic compounds remain in the liquid phase in the capsule. The container is dried and then sampled in the elemental analyser.

Section 3: The effects of crop and crop rotation on nitrous oxide emissions.

Soil-atmosphere exchange of nitrous oxide (N₂O) was measured using nonflow-through nonsteady-state chambers (Rochette et al. 2004). Briefly, acrylic frames were inserted about 5 cm into the soil over a seeded row and remained in place except during seeding and harvest. Care was taken to disturb the soil as little as possible during the installation process. Soil was back-filled around the outsides of the frame, and the inside was made level with the surrounding area to ensure a good seal between the soil and the frame. All subsequent plant growth was removed from inside the frame, and the area surrounding the chamber was re-seeded by hand. Acrylic lids, fitted with a closed-pore foam gasket, were attached to the frames during the sample collection time. The internal surface area was approximately 1000 cm² and the total volume of the enclosed headspace was about 10,000 cm³. Samples were drawn from the headspace at 15, 30 and 45 minute intervals by fully filling disposable 20 ml polypropylene syringes. The entire gas sample (to ensure a positive pressure in the exetainer) was then injected into pre-evacuated 13 ml exetainer™ glass tubes for transport to the laboratory.

The concentration of N₂O in samples was determined using a gas chromatograph equipped with an ⁶³Ni electron capture detector. The calculated minimum detectable difference for the system was <10 ppbv. N₂O flux was calculated from the rate of change in N₂O concentration over time, estimated by fitting a linear or quadratic plot to N₂O concentration versus time. Time zero values were estimated using a method similar to that described by Anthony et al. (1995). A series of ambient air samples were collected at each sampling time. The mean of these samples was used as the time zero concentration.

Samples were collected twice weekly at each plot from spring thaw until the beginning of the growing season. Sampling frequency is usually reduced to once weekly later in July and then to every other week in October. Cumulative estimates were calculated by interpolating between data points and integrating over time assuming a constant flux (Lemke et al., 1999).

Generally speaking, N₂O emissions have the highest concentration immediately after fertilizer application, when soil temperatures are high, during spring thaw and after rainfall events (degassing).

Section 4: The effects of crop and crop rotation on nutrient cycling.

On May 16, 2007, we buried two PVC cylinders in close proximity to each other in each plot in between two seeded rows. The cylinders were hammered into the ground, flush to the soil surface. The diameter of the cylinders was 10.14 cm and 15.24 cm in length (4" x 6"). Immediately after placing the cylinders in the soil, two Plant Root Simulator (PRST™) probes were placed into the soil in each cylinder. One consisted of an anionic membrane attracting

negative ions while the other one was a cationic membrane attracting positive ions (www.westernaglabs.com). After two weeks, both probes were removed from the cylinders, washed free of soil with distilled water and sent to the laboratory for analysis. Immediately another two strips was inserted into the cylinders. This was repeated three times such that we could estimate nutrient release after 2, 4 and 6 weeks. The sampling times were May 30th, June 13th and June 27th. The following anions were measured: nitrate-N, phosphorus (PO₄), sulfur (SO₄) and borate (B). The cations measured were calcium, manganese, potassium, magnesium, copper, zinc, iron, lead and aluminum.

Results and Discussion - Summary for 2005

Agronomic Information

On October 29, 2004, Avadex was applied at a rate of 1720 g ai/ha to all plots for fall site preparation. Early spring soil samples were collected April 22, 2005. One core was collected for each plot at depths of 0-12", 12-24" and 24-48". All samples were weighed before and after drying to calculate soil moisture, and then the samples were ground for N and P analyses. The test was seeded on April 26, 2005 as follows:

Crop	Cultivar	Rate (kg/ha)
Field Pea	Eclipse	194
Spring Wheat	Prodigy	134
Inoculant	LiphaTech	5.6
Phosphate Fertilizer	11-51-00	48
Fertilizer	Rate (Actual N)	Urea Product Rate (kg/ha)**
46-00-00	0	0
Starter N - Pea	20	32
Starter N - Pea	40	75
Wheat	80	162
** Rate calculated with N from 11-52-00 accounted for.		

Soil samples were collected on May 17, 2005 at depths of 0-3", 3-6" and 6-12" to quantify soil organic carbon and nitrogen. Plants counts were done on May 31, 2005. In-crop herbicide application of Odyssey and Merge was applied to pea plots on June 6, 2005 at a rate of 29.75 g ai/ha. Spring wheat plots were sprayed with Achieve and Buctril M at rates of 200 and 280 g ai/ha respectively on June 13, 2005. Due to a cool, wet growing season plots were not harvested until September 7, 2005. The total precipitation from seeding until harvest was 315.6 mm. Fall soil moisture samples were collected on September 15 and 16, 2005, at depths of 0-12", 12-24" and 24-48". Rhizobial soil samples were collected on September 19, 2005.

Section 1: The effects of crop and crop rotation on soil microbial biomass, diversity, enzyme activity and populations of rhizobia.

Enzyme activity for 2005 is still being determined in the laboratory.

In the rhizosphere, Rotation 1 had greater soil microbial biomass than Rotation 2, and Rotation 3 had greater microbial biomass than Rotations 1 and 2 (Tables 1.1 and 1.3). Therefore, the order of soil microbial biomass was: Rotation 3 > Rotation 1 > Rotation 2, i.e., soil microbial biomass decreased with increasing pea frequency in rotation. This order cannot be explained in terms of the sampled crop (wheat vs. pea) since the crop effect was not significant. Nitrogen fertilization of peas in Rotation 2 decreased microbial biomass. In bulk soil, Rotation 1 had greater soil microbial biomass than Rotation 3 (Tables 1.2 and 1.4), i.e., the reverse of the effect observed in the rhizosphere. Nitrogen fertilization of peas in Rotations 1 or 2 had no significant effects on microbial biomass, presumably because the fertilizer effect was confined to crop rows where it had been applied.

The diversity of bacteria (as measured by Shannon index, H') was greater in pea rhizosphere than that in wheat rhizosphere, but rotation had no significant effects (Tables 1.1 and 1.5). The pea rhizosphere effect on microbial diversity is probably due to legumes producing a greater variety of root exudates than cereals. Nitrogen fertilization of peas decreased bacterial diversity. In bulk soil, bacterial diversity was also greater under peas than that under wheat, and was greater in Rotation 3 than in Rotation 1 (Tables 1.2 and 1.6). This rotation effect is similar to the effect on microbial biomass in the rhizosphere. Nitrogen fertilization of peas had no significant effects.

The population of rhizobia was not affected by rotation, but the population in Rotation 2 (peas only) was reduced with N fertilization (Tables 1.2 and 1.7). This fertilizer effect is similar to the effect on microbial biomass in the rhizosphere because the soil for *Rhizobium* counts was sampled in crop rows, where the fertilizer had been applied.

These are one year's results and should be considered as preliminary. Some of the observations can be explained, e.g., the negative effects of fertilizer on soil microbes in bulk soil are probably through soil acidity or osmotic pressure, but others cannot be explained yet and they need to be confirmed by future results, e.g., the decrease in microbial biomass in the rhizosphere with increasing pea frequency in rotation. However, the statistically significant rotation effects on soil microbial biomass and diversity (in bulk soil), but not on organic C or N (see below),

underlines the value of microbiological parameters as sensitive indicators of soil biological quality.

Table 1.1. P-values from the analysis of variance of microbial biomass C and diversity (Shannon index, H') of bacteria in the rhizosphere in 2005.

Source	df	Microbial biomass	Shannon Index (H')
Treatment (T)	11	0.02	0.002
Replicate	3	ns ¹	ns
Contrasts			
Spring wheat vs field pea		ns	0.0001
Rot 1 vs Rot 2		0.051	ns
Rot 1 vs Rot 3		0.009	ns
Rot 2 vs Rot 3		0.0002	ns
Rot 1 (pea only) 0 vs 20&40		ns	ns
Rot 1 (pea only) 20 vs 40		ns	ns
Rot 2 (pea only) 0 vs 20&40		ns	ns
Rot 2 (pea only) 20 vs 40		0.068	ns
Rot 1& 2 (pea only) 0 vs 20&40		ns	ns
Rot 1&2 (pea only) 20 vs 40		0.088	ns
0 N vs Rest N		ns	0.015
¹ ns signifies not significant.			

Table 1.2. P-values from the analysis of variance of microbial biomass C, bacterial diversity (Shannon index, H') and populations of rhizobia in bulk soil in 2005.

Source	df	Microbial biomass	Shannon index (H)	<i>Rhizobium</i> population ¹
Treatment (T)	11	ns ²	ns	ns
Replicate	3	0.08	ns	0.008
Contrasts				
Spring wheat vs field pea		ns	0.090	ns
Rot 1 vs Rot 2		ns	ns	ns
Rot 1 vs Rot 3		0.047	0.056	ns
Rot 2 vs Rot 3		ns	ns	ns
Rot 1 (pea only) 0 vs 20&40		ns	ns	ns
Rot 1 (pea only) 20 vs 40		ns	ns	ns
Rot 2 (pea only) 0 vs 20&40		0.075	ns	0.071
Rot 2 (pea only) 20 vs 40		ns	ns	ns
Rot 1 & 2 (pea only) 0 vs 20&40		0.065	ns	ns
Rot 1&2 (pea only) 20 vs 40		ns	ns	ns
0 N vs Rest N		ns	ns	ns
¹ Rhizobium populations were only determined on soil samples taken in the row. ² ns signifies not significant.				

Table 1.3. The effects of crop, rotation and nitrogen fertilizer rate on microbial biomass C (mg CO₂-C/kg soil) in the rhizosphere in 2005.

Crop	N (kg/ha)	Rotation 1	Rotation 2	Rotation 3
Field Pea	0	892	655	899
	20	799	765	-
	40	823	475	-
Spring wheat	80 ¹	712	-	-
	80 ²	845	-	1137
	80 ³	653	-	970
¹ In rotation 1, spring wheat was seeded on field pea which had received 0 kg N ha ⁻¹ the previous year. ² In rotation 1, spring wheat was seeded on field pea which had received 20 kg N ha ⁻¹ the previous year. In rotation 3, spring wheat was seeded on spring wheat stubble which had received 80 kg N ha ⁻¹ . ³ In rotation 1, spring wheat was seeded on field pea which had received 40 kg N ha ⁻¹ the previous year. In rotation 3, spring wheat was seeded on field pea stubble which had received 0 kg N ha ⁻¹ .				

Table 1.4. The effects of crop, rotation and nitrogen fertilizer rate on microbial biomass C (mg CO₂-C/kg soil) in bulk soil in 2005.

Crop	N (kg/ha)	Rotation 1	Rotation 2	Rotation 3
Field Pea	0	866	810	802
	20	917	998	-
	40	978	947	-
Spring wheat	80 ¹	920	-	-
	80 ²	1051	-	963
	80 ³	964	-	761
¹ In rotation 1, spring wheat was seeded on field pea which had received 0 kg N ha ⁻¹ the previous year. ² In rotation 1, spring wheat was seeded on field pea which had received 20 kg N ha ⁻¹ the previous year. In rotation 3, spring wheat was seeded on spring wheat stubble which had received 80 kg N ha ⁻¹ . ³ In rotation 1, spring wheat was seeded on field pea which had received 40 kg				

N ha⁻¹ the previous year. In rotation 3, spring wheat was seeded on field pea stubble which had received 0 kg N ha⁻¹.

Table 1.5. The effects of crop, rotation and nitrogen fertilizer rate on the diversity (Shannon index, H') of bacteria in the rhizosphere in 2005.

Crop	N (kg/ha)	Rotation 1	Rotation 2	Rotation 3
Field Pea	0	2.99	2.92	2.95
	20	2.93	2.93	-
	40	2.95	2.87	-
Spring wheat	80 ¹	2.88	-	-
	80 ²	2.70	-	2.77
	80 ³	2.87	-	2.81

¹ In rotation 1, spring wheat was seeded on field pea which had received 0 kg N ha⁻¹ the previous year.

² In rotation 1, spring wheat was seeded on field pea which had received 20 kg N ha⁻¹ the previous year. In rotation 3, spring wheat was seeded on spring wheat stubble which had received 80 kg N ha⁻¹.

³ In rotation 1, spring wheat was seeded on field pea which had received 40 kg N ha⁻¹ the previous year. In rotation 3, spring wheat was seeded on field pea stubble which had received 0 kg N ha⁻¹.

Table 1.6. The effects of crop, rotation and nitrogen fertilizer rate on the diversity (Shannon index, H') of bacteria in bulk soil in 2005.

Crop	N (kg/ha)	Rotation 1	Rotation 2	Rotation 3
Field Pea	0	2.30	1.98	2.85
	20	2.03	2.50	-
	40	2.50	2.24	-
Spring wheat	80 ¹	2.05	-	-
	80 ²	1.90	-	2.15
	80 ³	1.83	-	2.47

¹ In rotation 1, spring wheat was seeded on field pea which had received 0 kg N ha⁻¹ the previous year.

² In rotation 1, spring wheat was seeded on field pea which had received 20 kg N ha⁻¹ the previous year. In rotation 3, spring wheat was seeded spring wheat stubble which had received 80 kg N ha⁻¹.

³ In rotation 1, spring wheat was seeded on field pea which had received 40 kg N ha⁻¹ the previous year. In rotation 3, spring wheat was seeded field pea stubble which had received 0 kg N ha⁻¹.

Table 1.7. The effects of crop, rotation and nitrogen fertilizer rate on the population of rhizobia (# g⁻¹ soil) in bulk soil in 2005.

Crop	N (kg/ha)	Rotation 1	Rotation 2	Rotation 3
Field Pea	0	738	6881	7547
	20	359	1260	-
	40	607	423	-
Spring wheat	80 ¹	5337	-	-
	80 ²	357	-	329
	80 ³	1004	-	2072

¹ In rotation 1, spring wheat was seeded on field pea which had received 0 kg N ha⁻¹ the previous year.

² In rotation 1, spring wheat was seeded on field pea which had received 20 kg N ha⁻¹ the previous year. In rotation 3, spring wheat was seeded on spring wheat stubble which had received 80 kg N ha⁻¹.

³ In rotation 1, spring wheat was seeded on field pea which had received 40 kg N ha⁻¹ the previous year. In rotation 3, spring wheat was seeded on field pea stubble which had received 0 kg N ha⁻¹.

Section 2: The effects of crop and crop rotation on soil bulk density, soil organic carbon and nitrogen.

The first question of interest is the effects of crop rotation ie. frequency of legumes in rotation, on soil bulk density. According to the results presented in Table 2.1, crop rotation, after 11 years, had no effect on soil bulk density for the three depths measured. It should be noted that for the 0-3" soil layer, the tendency was for rotation 1 to have a slightly higher soil bulk density than rotation 2 and rotation 3. However, the absolute difference was only on the order of 0.08 g cm^{-3} . In order to report the results for soil organic carbon and nitrogen on a mass basis, we used a soil bulk density value of 0.97 g cm^{-3} for the 0-3" soil layer and 1.38 g cm^{-3} for the 3-6" soil layer, given the lack of statistical significance.

Table 2.1. The effects of crop rotation and starter nitrogen in field pea on soil bulk density (g/cm^3). The results are from samples collected in 2005.

Soil Layer	Rotation 1 (Pea -wheat)	Rotation 2 (Cont. Pea)	Rotation 3 (Wheat -Wheat-Pea)	p-value
0-3"	1.01	0.92	0.94	0.066
3-6"	1.38	1.38	1.37	0.83
6-12"	1.42	1.40	1.45	0.27

The second question of interest is the effects of crop rotation on soil organic carbon and nitrogen after 11 years with the various treatments. We are interested in knowing if increasing the frequency of grain legumes like field pea in a rotation can accelerate carbon sequestration. A summary of the p-values from the analysis of variance for soil organic carbon is provided in Table 2.2. A rotation effect was observed for the 0-3" soil layer from the 1994 soil samples before the study started reflecting effects of spatial variability. No differences were observed in 2005 due to rotation. An effect of an increase in carbon due to rotation was observed for the 0-3" soil layer. This is essentially measuring carbon sequestration. No important differences were observed for the 3-6" soil layer. A summary of the results is provided in Table 2.3. According to the results the carbon sequestered per year after 10 years for the 0-6" soil layer in rotation 1 sequestered $275 \text{ kg C ha}^{-1} \text{ year}^{-1}$, rotation 2 sequestered $472 \text{ kg C ha}^{-1} \text{ year}^{-1}$ and rotation 361 $\text{kg C ha}^{-1} \text{ year}^{-1}$. One could argue that the amount of carbon sequestered with continuous grain legumes was the largest supporting the notion that increasing the frequency of grain legumes in the rotation accelerates carbon sequestration. However rotation 3 had more carbon sequestered than rotation 1 and rotation 3 has field pea every three years as opposed to every second year in rotation 2.

Table 2.2. P-values from the analysis of variance of soil organic carbon for two soil depths and for two different years of sampling.

Source	df	0-3" Soil Layer			3-6" Soil Layer		
		1994	2005	Difference (2005-1994)	1994	2005	Difference (2005-1994)
Rotation (R)	2	0.019	0.28	0.038	0.83	0.31	0.094
Nitrogen (N)	3	0.63	0.51	0.79	0.31	0.51	0.044
Rep	3	0.036	0.12	0.41	0.005	0.08	0.29
R x N	3	0.78	0.44	0.51	0.65	0.21	0.013
cv (%)		15.5	13.0	98.5	17.6	15.1	176

Table 2.3. The effects of crop rotation on soil organic carbon (SOC) from soil samples taken in the fall of 1994 and spring of 2005.

Variable (kg/ha)	Soil Depth	Year	Rotation 1 (Pea - wheat)	Rotation 2 (Cont. Pea)	Rotation 3 (Wheat - Wheat-Pea)	Mean	p-value
SOC	0-3"	1994	19002	16253	16514	17693	0.008
		2005	20141	18002	19210	19373	0.068
		Difference (2005-1994)	1139	1749	2696	1681	0.03
SOC	3-6"	1994	19542	19327	20006	19604	ns
		2005	21148	22297	20920	21378	ns
		Difference (2005-1994)	1606	2970	913	1774	ns
SOC	0-6"	1994	38543	35580	36520	37297	ns
		2005	41289	40299	40130	40751	ns
		Difference (2005-1994)	2746	4719	3610	3454	-

The increase in soil organic nitrogen follows a similar path as organic carbon. A summary of the p-values from the analysis of variance for soil organic nitrogen is provided in Table 2.4. A difference in soil organic nitrogen was observed for the 0-3" soil layer in 1994 at the start of the experiment reflecting differences due to spatial variability. The difference in soil organic N between 2005 and 1994 was recorded as $p=0.082$ for the 0-3" soil layer and $p=0.079$ for the 3-6" soil layer indicating that some rotation effects were observed. The results in Table 2.5 show the largest differences in favor of rotation 2, followed by rotation 3 then rotation 1. The results are similar to soil organic carbon.

Based on the results obtained to date, we cannot say that carbon sequestration is increased with the increase in frequency of field pea in the rotation but continuous pea is definitely showing the largest values.

Table 2.4. P-values from the analysis of variance of soil organic nitrogen for two soil depths and for two different years of sampling.

Source	df	0-3" Soil Layer			3-6" Soil Layer		
		1994	2005	Difference (2005-1994)	1994	2005	Difference (2005-1994)
Rotation (R)	2	0.054	0.34	0.082	0.77	0.39	0.079
Nitrogen (N)	3	0.68	0.34	0.030	0.43	0.70	0.064
Rep	3	0.13	0.10	0.83	0.039	0.29	0.64
R x N	3	0.65	0.65	0.435	0.457	0.39	0.009
cv (%)		15.4	12.9	97.7	14.2	13.5	157.3

Table 2.5. The effects of crop rotation on soil organic nitrogen (SON) from soil samples taken in the fall of 1994 and spring of 2005.

Variable (kg/ha)	Soil Depth	Year	Rotation 1 (Pea - wheat)	Rotation 2 (Cont. Pea)	Rotation 3 (Wheat - Wheat-Pea)	Mean	p-value
SON	0-3"	1994	1806	1574	1610	1699	0.025
		2005	1914	1711	1826	1841	0.067
		Difference (2005-1994)	108	137	216	142	0.082
SON	0-6"	1994	1916	1909	1927	1917	ns
		2005	2073	2136	2025	2077	ns
		Difference (2005-1994)	157	227	98	160	0.07
SON	0-6"	1994	3721	3483	3537	3615	ns
		2005	3988	3847	3850	3918	ns
		Difference (2005-1994)	267	364	313	303	-

Section 3: The effects of crop and crop rotation on nitrous oxide emissions.

Cumulative estimates of N₂O loss during the growing season and fall of 2005 were between 53 and 121 grams N/ha. The growing season started off with more than average amounts of precipitation in the months of May and June, and then ended with below normal precipitation in the months of July and August. This could explain the lower amounts of N₂O loss during the growing season and fall of 2005. Another possible explanation would be lower amounts of soil residual N due to above average precipitation over the last couple of years. Emissions were highest when wheat was present on pea residue every second year (121 g N ha⁻¹ yr⁻¹), intermediate when pea was cropped continuously (79 g N ha⁻¹ yr⁻¹), and emissions were lowest when pea was present on wheat residue every third year (53 g N ha⁻¹ yr⁻¹).

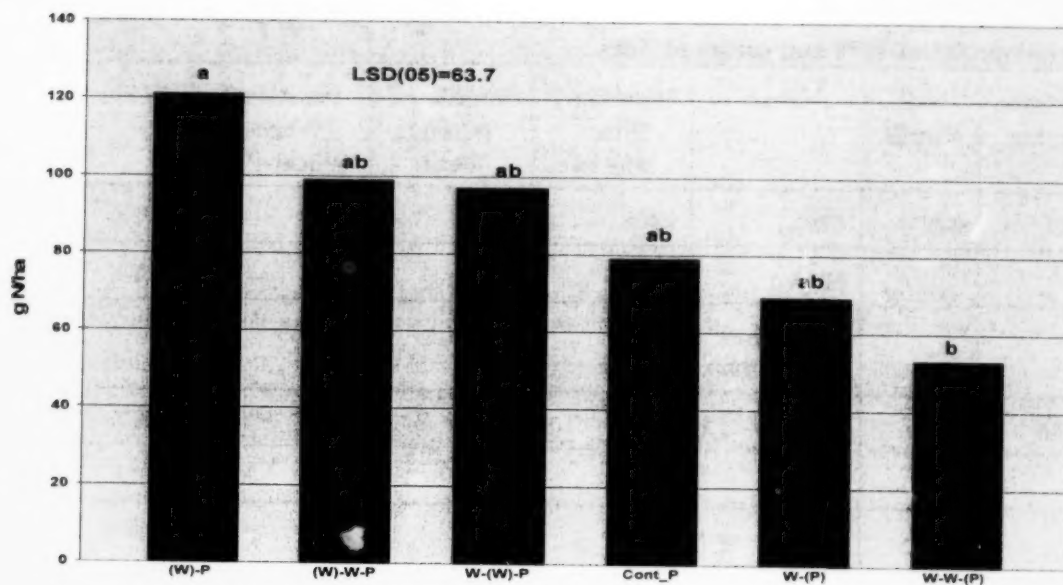


Figure 1. Estimated cumulative N₂O loss from selected treatments during the 2005 growing season and fall period at Indian Head, Saskatchewan.

W = spring wheat; P = pea; Cont P = continuous pea (pea crop grown every year)

Brackets indicate which crop phase was present during sampling.

Conclusions

Pea phases tend to have lower emissions during the growing season than wheat phases. When pea residues are present during spring thaw there may be a 'hot spot' of N₂O emissions compared to wheat residues, but this is offset by lower emissions during the pea phase. These results suggest that N₂O emissions are not significantly higher on the long-term no-till system, even though other indications (yield, grain protein etc.) suggest that the N supplying capacity of the soil has increased markedly.

Results and Discussion - Summary for 2006

Agronomic Information

Spring soil moisture samples were collected May 15, 2006. One core was collected for each plot using increments of 0-30 cm, 30-60 cm, and 60-120 cm. All samples were weighed before and after drying to calculate total soil moisture, and then the samples were ground for N and P analyses. The test was seeded on May 4, 2006 as follows:

Crop	Cultivar	Rate (kg/ha)
Field Pea	Eclipse	194
Spring Wheat	Prodigy	134
Inoculant	LiphaTech	5.6
Phosphate Fertilizer	11-51-00	48
Fertilizer	Rate (Actual N)	Urea Product Rate (kg/ha)**
46-00-00	0	0
Starter N - Pea	20	32
Starter N - Pea	40	75
Wheat	80	162
** Rate calculated with N from 11-52-00 accounted for.		

Plants counts were done on May 30, 2006. In-crop herbicide application of Odyssey and Merge was applied to pea plots on June 6, 2006 at a rate of 30 g ai/ha. Spring wheat plots were sprayed with Achieve and Attain at a rate of 872 g ai/ha respectively on June 7, 2006. Rhizosphere and non-rhizosphere soil samples were collected on June 30, 2006. Nematode samples were collected on July 4, 2006. Pea plots were sprayed with Reglone at a rate of 350 g ai/ha on August 8, 2006. Wheat plots were harvested on August 15, 2006 and pea plots were harvested on August 16, 2006. Fall soil moisture samples were collected on August 18, 2006, at depths of 0-30 cm, 30-60 cm, and 60-120 cm. Rhizosphere and non-rhizosphere soil samples were collected on September 20, 2006 on all plots. Soil P samples on wheat-pea and continuous pea rotations were collected on October 23, 2006.

Section 1: The effects of crop and crop rotations on soil microbial biomass, diversity, enzyme activity and populations of rhizobia.

Soil microbial biomass and diversity in 2006 samples are still being determined in the laboratory.

Soil enzymes are mostly of microbial origin. Enzyme activities are important soil quality indicators because they are often closely related to important soil quality parameters like organic matter, soil physical properties and microbial activity and biomass. They begin to change much sooner (1-2 yr) than other properties and can be an integrative soil biological index of past soil management. Enzymes involved in the C cycle are good choices as soil quality indicators, and β -glucosidase is an important enzyme in releasing C for energy.

β -glucosidase enzyme activity results for both 2005 and 2006 are reported here because 2005 results were not reported in the 2005 report. In 2005 in the rhizosphere, enzyme activity was in the order: Rotation 3 > Rotation 1 > Rotation 2, i.e., enzyme activity decreased with increasing pea frequency in rotation (Table 1.2). This order corresponds with that of soil microbial biomass in 2005. The crop effects on enzyme activity seem to explain these results, i.e., β -glucosidase activity was greater in the rhizosphere of spring wheat than in pea rhizosphere (Table 1.2). However, enzyme activity was also greater where N was applied than where it was not applied (Table 1.2), and this is probably the real explanation for the crop effects because wheat received up to 80 kg N ha⁻¹ and pea only up to 40 kg N ha⁻¹. In bulk soil (non-rhizosphere), enzyme activity was in the order: Rotation 1 > Rotation 2 = Rotation 3, and 0 N < Rest of N. The decomposition of crop residues from preceding crops probably also affected enzyme activities in bulk soil.

In 2006 in the rhizosphere, the order of enzyme activity was: Rotation 3 = Rotation 1 > Rotation 2, wheat rhizosphere > pea rhizosphere, and 0 N < Rest of N (Table 1.4), i.e., the continuous pea rotation had the lowest enzyme activity, probably because it received less N fertilizer than the other rotations. However, in bulk soil, the order of enzyme activity was: Rotation 2 > Rotation 1 = Rotation 3 (Table 1.3), presumably because crop residue effects become more important than fertilizer effects in bulk soil.

The population of rhizobia in 2006 was not affected by rotation or N fertilizer, but the population under wheat was greater than that under pea (Table 1.5). These results are different from those observed in 2005, when the population in Rotation 2 (peas only) was reduced with N fertilization. In 2005, the soil for *Rhizobium* counts was sampled in crop rows, where the fertilizer had been applied, but the soil samples in 2006 consisted of equal proportions of intra-row and inter-row samples. This was a technical oversight, and intra-row sampling will be done in 2007. By combining intra-row and inter-row samples, the effects of N fertilizer (mostly intra-row) and decomposing crop residues (mostly inter-row) could not be separated. The greater population of rhizobia under wheat than under pea may be due to preceding crop effects.

Table 1.1. The effects of crop, rotation and N rate on β -Glucosidase enzyme activity (mg nitrophenol/kg soil/hr) in 2005 in the non-rhizosphere portion of the soil.

Crop	N (kg/ha)	Rotation 1 ^z	Rotation 2	Rotation 3
Field Pea	0	373	374	379
	20	393	405	-
	40	457	384	-
Spring wheat	80 (0)	465	-	-
	80 (20)	425	-	400 y
	80 (40)	450	-	379 x
		LSD(05)=43		
Contrast		Pr>F		
SWHT VS PEA		0.1200		
ROT1 VS ROT2		0.0355		
ROT1 VS ROT3		0.0102		
ROT2 VS ROT3		0.6469		
ROT1(PEA) 0 VS 20+40		0.1077		
ROT1(PEA) 20 VS 40		0.0853		
ROT2(PEA) 0 VS 20+40		0.5154		
ROT2(PEA) 20 VS 40		0.5614		
ROT1& ROT2 0 VS 20+40		0.1117		
ROT1&ROT2 20 VS 40		0.4072		
0 N VS REST N		0.0276		

^z Rotation 1=pea-wheat-wheat; Rotation 2=continuous field pea; Rotation 3= pea -wheat-wheat

^y Spring wheat on spring wheat stubble

^x Spring wheat on pea stubble

Table 1.2. The effects of crop, rotation and N rate on β -Glucosidase enzyme activity (mg nitrophenol/kg soil/hr) in 2005 in the rhizosphere portion of the soil.

Crop	N (kg/ha)	Rotation 1z	Rotation 2	Rotation 3																								
Field Pea	0	245	204	248																								
	20	254	259	-																								
	40	240	227	-																								
Spring wheat	80 (0)	305	-	-																								
	80 (20)	339	-	413y																								
	80 (40)	305	-	367x																								
		LSD(05)=51																										
<table><tr><th>Contrast</th><th>Pr > F</th></tr><tr><td>SWHT VS PEA</td><td><0.0001</td></tr><tr><td>ROT1 VS ROT2</td><td>0.0244</td></tr><tr><td>ROT1 VS ROT3</td><td>0.0078</td></tr><tr><td>ROT2 VS ROT3</td><td><0.0001</td></tr><tr><td>ROT1PEA 0VS20+40</td><td>0.9608</td></tr><tr><td>ROT1PEA 20 VS 40</td><td>0.7377</td></tr><tr><td>ROT2PEA 0VS20+40</td><td>0.3053</td></tr><tr><td>ROT2PEA 20 VS 40</td><td>0.4792</td></tr><tr><td>R1&R2 0 VS 20+40</td><td>0.4460</td></tr><tr><td>R1&R2 20 VS 40</td><td>0.4616</td></tr><tr><td>0 N VS REST N</td><td>0.0021</td></tr></table>					Contrast	Pr > F	SWHT VS PEA	<0.0001	ROT1 VS ROT2	0.0244	ROT1 VS ROT3	0.0078	ROT2 VS ROT3	<0.0001	ROT1PEA 0VS20+40	0.9608	ROT1PEA 20 VS 40	0.7377	ROT2PEA 0VS20+40	0.3053	ROT2PEA 20 VS 40	0.4792	R1&R2 0 VS 20+40	0.4460	R1&R2 20 VS 40	0.4616	0 N VS REST N	0.0021
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0 N VS REST N	0.0021																											

^z Rotation 1=pea-wheat-wheat; Rotation 2=continuous field pea; Rotation 3= pea -wheat-wheat

^y Spring wheat on spring wheat stubble

^x Spring wheat on pea stubble

Table 1.3. The effects of crop, rotation and N rate on β -Glucosidase enzyme activity (mg nitrophenol/kg soil/hr) in 2006 in the non-rhizosphere portion of the soil.

Crop	N (kg/ha)	Rotation 1z	Rotation 2	Rotation 3
Field Pea	0	430	380	460
	20	451	419	-
	40	461	694	-
Spring wheat	80 (0)	424	-	-
	80 (20)	451	-	416 y
	80 (40)	451	-	432x
LSD(05)=37				
Contrast		Pr>F		
SWHT VS PEA		0.600		
ROT1 VS ROT2		0.006		
ROT1 VS ROT3		0.583		
ROT2 VS ROT3		0.045		
ROT1(PEA) 0 VS 20+40		0.636		
ROT1(PEA) 20 VS 40		0.761		
ROT2(PEA) 0 VS 20+40		0.343		
ROT2(PEA) 20 VS 40		0.428		
ROT1& ROT2 0 VS 20+40		0.192		
ROT1&ROT2 20 VS 40		0.728		
0 N VS REST N		0.522		

^z Rotation 1=pea-wheat-wheat; Rotation 2=continuous field pea; Rotation 3= pea -wheat-wheat

^y Spring wheat on spring wheat stubble

^x Spring wheat on pea stubble

Table 1.4. The effects of crop, rotation and N rate on β -Glucosidase enzyme activity (mg nitrophenol/kg soil/hr) in 2006 in the rhizosphere portion of the soil.

Crop	N (kg/ha)	Rotation 1z	Rotation 2	Rotation 3
Field Pea	0	296	276	313
	20	266	250	-
	40	328	317	-
Spring wheat	80 (0)	360	-	-
	80 (20)	395	-	418y
	80 (40)	401	-	415x
		LSD(05)=65		
Contrast		Pr>F		
SWHT VS PEA		0.001		
ROT1 VS ROT2		0.037		
ROT1 VS ROT3		0.151		
ROT2 VS ROT3		0.003		
ROT1(PEA) 0 VS 20+40		0.928		
ROT1(PEA) 20 VS 40		0.272		
ROT2(PEA) 0 VS 20+40		0.875		
ROT2(PEA) 20 VS 40		0.234		
ROT1& ROT2 0 VS 20+40		0.899		
ROT1&ROT2 20 VS 40		0.109		
0 N VS REST N		0.044		

^z Rotation 1=pea-wheat-wheat; Rotation 2=continuous field pea; Rotation 3= pea -wheat-wheat

^y Spring wheat on spring wheat stubble

^x Spring wheat on pea stubble

Table 1.5. The effects of crop, rotation and N rate on MPN (most probable number) in 2006 in the non-rhizosphere portion of the soil.

Crop	N (kg/ha)	Rotation 1z	Rotation 2	Rotation 3
Field Pea	0	3302	11843	114979
	20	50830	54766	-
	40	1774	1095	-
Spring wheat	80 (0)	58730	-	-
	80 (20)	2694	-	53624 ^y
	80 (40)	150742	-	48936 ^x
		LSD(05)=57044		
Contrast		Pr>F		
SWHT VS PEA		0.016		
ROT1 VS ROT2		0.370		
ROT1 VS ROT3		0.260		
ROT2 VS ROT3		0.080		
ROT1(PEA) 0 VS 20+40		0.590		
ROT1(PEA) 20 VS 40		0.310		
ROT2(PEA) 0 VS 20+40		0.700		
ROT2(PEA) 20 VS 40		0.270		
ROT1& ROT2 0 VS 20+40		0.520		
ROT1&ROT2 20 VS 40		0.140		
0 N VS REST N		0.870		
^z Rotation 1=pea-wheat-wheat; Rotation 2=continuous field pea; Rotation 3= pea -wheat-wheat				
^y Spring wheat on spring wheat stubble				
^x Spring wheat on pea stubble				

Section 2: The effects of crop and crop rotation on soil bulk density, soil organic carbon and nitrogen.

No samples collected in 2006. Refer to 2005 results for details.

Section 3: The effects of crop and crop rotation on nitrous oxide emissions.

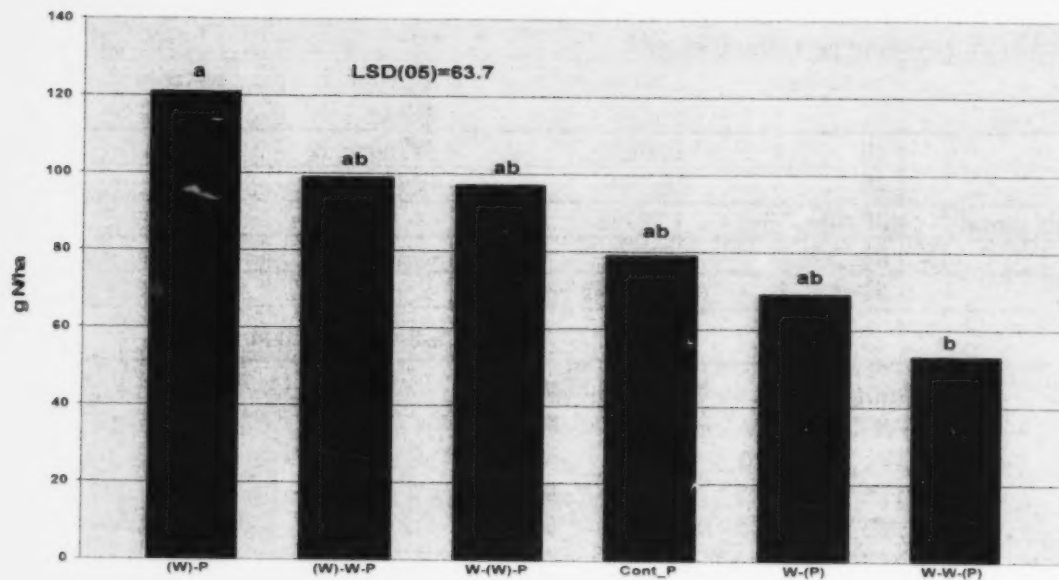


Figure 1. Estimated cumulative N₂O loss from selected treatments during the 2006 growing season and fall period at Indian Head, Saskatchewan.

W = spring wheat; P = pea; ContP = continuous pea (pea crop grown every year)
Brackets indicate which crop phase was present during sampling.

Cumulative estimates of N₂O loss during the growing season and fall of 2006 were between 53 and 121 grams N/ha. The growing season started off with more than average amounts of precipitation in the months of May and June, and then ended with below normal precipitation in the months of July and August. This could explain the lower amounts of N₂O loss during the growing season and fall of 2006. Another possible explanation would be lower amounts of soil residual N due to above average precipitation over the last couple of years. Emissions were highest when wheat was present on pea residue every second year (121 g N ha⁻¹ yr⁻¹), intermediate when pea was cropped continuously (79 g N ha⁻¹ yr⁻¹), and emissions were lowest when pea was present on wheat residue every third year (53 g N ha⁻¹ yr⁻¹).

Conclusions

Pea phases tend to have lower emissions during the growing season than wheat phases. When pea residues are present during spring thaw there may be a 'hot spot' of N₂O emissions compared to wheat residues, but this is offset by lower emissions during the pea phase. These results suggest that N₂O emissions are not significantly higher on the long-term no-till system, even though other indications (yield, grain protein etc.) suggest that the N supplying capacity of the soil has increased markedly.

Results and Discussion - Summary for 2007

Agronomic Information

Spring soil moisture samples were collected on April 20th, 2007. One core was collected for each plot using increments of 0-30 cm, 30-60 cm, and 60-120 cm. All samples were weighed before and after drying to calculate total soil moisture, and then the samples were ground for N and P analyses. The test was seeded on April 26, 2007 as follows:

Crop	Cultivar	Rate (kg/ha)
Field Pea	Eclipse	194
Spring Wheat	Prodigy	134
Inoculant	LiphaTech	5.6
Phosphate Fertilizer	11-51-00	48
Fertilizer	Rate (Actual N)	Urea Product Rate (kg/ha)**
46-00-00	0	0
Starter N - Pea	20	32
Starter N - Pea	40	75
Wheat	80	162
** Rate calculated with N from 11-52-00 accounted for.		

Plants counts were done on May 18th, 2007. In-crop herbicide application of Odyssey and Merge was applied to pea plots on June 4, 2007 at a rate of 30 g ai/ha. Spring wheat plots were sprayed with Achieve and Attain at a rate of 872 g ai/ha respectively on June 4, 2007 (Attain(A-.24 l/acre B-.4 l/acre)+Achieve(.2 l/acre)+Turbo charge(.22 l/acre).

Rhizosphere and Non-rhizosphere soil samples were collected on July 6th, 2007. Wheat plots were harvested on August 24, 2007 and pea plots were harvested on August 16, 2007. Fall soil moisture samples were collected on August 18, 2006, at depths of 0-30 cm, 30-60 cm, and 60-120 cm.

Section 1: The effects of crop and crop rotations on soil microbial biomass, diversity, enzyme activity and populations of rhizobia.

There were no significant treatment effects on soil microbial biomass, diversity or enzyme activity in wheat or pea rhizosphere in 2007 (Table 1.1 & 1.3 & 1.5). In bulk soil, microbial biomass in spring wheat was greater than that in field pea (Table 1.2 & 1.4 & 1.6). Application of N in pea increased soil microbial biomass relative to the control without applied N, and the pea phase of Rotation 1 (wheat-pea) had greater microbial biomass than that of Rotation 2 (continuous pea). Bacterial diversity in bulk soil was not affected by any treatment in 2007.

β -glucosidase enzyme activity in bulk soil was greater in wheat than in field pea, and greater in the wheat phase of Rotation 1 (wheat-pea) than that of Rotation 3 (wheat-wheat-pea) (Table 1.1 & 1.8)). This is in agreement with bulk soil results in 2005, but the difference between these two rotations was not significant in 2006, when enzyme activity in Rotation 2 (pea-pea) was greater than that in Rotation 1. Therefore, while enzyme activities tended to decrease with increasing pea frequency in the rhizosphere, the reverse tended to be true in bulk soil in the three seasons of study (Table 1.2 & 1.7).

Table 1.1. P-values from the analysis of variance of microbial biomass C, diversity (Shannon index, H') and of bacteria in the rhizosphere in 2007.

Source	df	Microbial biomass	Shannon Index (H')	β -Glucosidase enzyme activity
Treatment (T)	11	ns ¹	ns	ns
Replicate	3	ns	ns	ns
Contrast				
Spring wheat vs field pea		ns	ns	0.0094
Pea: Starter N vs No N		ns	ns	ns
Pea: Rot 1 vs Rot 2		ns	ns	ns
Pea: Rot 2 vs Rot 3		ns	ns	ns
Pea: Rot 1 vs Rot 3		ns	ns	ns
Wheat: Rot 1 vs Rot 3		ns	ns	ns
Wheat Rot 3: Pea vs Wheat Stubble		ns	ns	ns
¹ ns signifies not significant.				

Table 1.2. P-values from the analysis of variance of microbial biomass C and bacterial diversity (Shannon index, H') in bulk soil in 2007.

Source	df	Microbial biomass	Shannon index (H)	β -Glucosidase enzyme activity
Treatment (T)	11	0.0037	ns ¹	
Replicate	3	0.024	ns	ns
Contrast				
Spring wheat vs field pea		0.002	ns	0.0011
Pea: Starter N vs No N		0.099	ns	ns
Pea: Rot 1 vs Rot 2		0.099	ns	ns
Pea: Rot 2 vs Rot 3		ns	ns	ns
Pea: Rot 1 vs Rot 3		ns	ns	ns
Wheat: Rot 1 vs Rot 3		ns	ns	0.0198
Wheat Rot 3: Pea vs Wheat Stubble		ns	ns	ns
¹ ns signifies not significant.				

Table 1.3. The effects of crop, rotation and nitrogen fertilizer rate on microbial biomass C (mg CO₂-C/kg soil) in the rhizosphere in 2007.

Crop	N (kg/ha)	Rotation 1	Rotation 2	Rotation 3
Field Pea	0	910	808	846
	20	1050	839	-
	40	918	839	-
Spring wheat	80 ¹	993	-	-
	80 ²	1116	-	973
	80 ³	970	-	988
¹ In rotation 1, spring wheat was seeded on field pea which had received 0 kg N ha ⁻¹ the previous year. ² In rotation 1, spring wheat was seeded on field pea which had received 20 kg N ha ⁻¹ the previous year. In rotation 3, spring wheat was seeded on spring wheat stubble which had received 80 kg N ha ⁻¹ .				

³ In rotation 1, spring wheat was seeded on field pea which had received 40 kg N ha⁻¹ the previous year. In rotation 3, spring wheat was seeded on field pea stubble which had received 0 kg N ha⁻¹.

Table 1.4. The effects of crop, rotation and nitrogen fertilizer rate on microbial biomass C (mg CO₂-C/kg soil) in bulk soil in 2007.

Crop	N (kg/ha)	Rotation 1	Rotation 2	Rotation 3
Field Pea	0	1060	866	1027
	20	1108	1002	-
	40	1080	1023	-
Spring wheat	80 ¹	1232	-	-
	80 ²	1244	-	1184
	80 ³	1097	-	1224

¹ In rotation 1, spring wheat was seeded on field pea which had received 0 kg N ha⁻¹ the previous year.

² In rotation 1, spring wheat was seeded on field pea which had received 20 kg N ha⁻¹ the previous year. In rotation 3, spring wheat was seeded on spring wheat stubble which had received 80 kg N ha⁻¹.

³ In rotation 1, spring wheat was seeded on field pea which had received 40 kg N ha⁻¹ the previous year. In rotation 3, spring wheat was seeded on field pea stubble which had received 0 kg N ha⁻¹.

Table 1.5. The effects of crop, rotation and nitrogen fertilizer rate on the diversity (Shannon index, H') of bacteria in the rhizosphere in 2007.

Crop	N (kg/ha)	Rotation 1	Rotation 2	Rotation 3
Field Pea	0	2.9	2.6	2.8
	20	3.0	2.5	-
	40	2.6	2.7	-
Spring wheat	80 ¹	2.7	-	-
	80 ²	2.6	-	2.9
	80 ³	2.5	-	2.7

¹ In rotation 1, spring wheat was seeded on field pea which had received 0 kg N ha⁻¹ the

previous year.

² In rotation 1, spring wheat was seeded on field pea which had received 20 kg N ha⁻¹ the previous year. In rotation 3, spring wheat was seeded on spring wheat stubble which had received 80 kg N ha⁻¹.

³ In rotation 1, spring wheat was seeded on field pea which had received 40 kg N ha⁻¹ the previous year. In rotation 3, spring wheat was seeded on field pea stubble which had received 0 kg N ha⁻¹.

Table 1.6. The effects of crop, rotation and nitrogen fertilizer rate on the diversity (Shannon index, H') of bacteria in the bulk soil in 2007.

Crop	N (kg/ha)	Rotation 1	Rotation 2	Rotation 3
Field Pea	0	2.6	2.0	2.4
	20	2.5	2.1	-
	40	2.3	2.2	-
Spring wheat	80 ¹	2.5	-	-
	80 ²	2.4	-	2.5
	80 ³	2.6	-	2.5

¹ In rotation 1, spring wheat was seeded on field pea which had received 0 kg N ha⁻¹ the previous year.

² In rotation 1, spring wheat was seeded on field pea which had received 20 kg N ha⁻¹ the previous year. In rotation 3, spring wheat was seeded on spring wheat stubble which had received 80 kg N ha⁻¹.

³ In rotation 1, spring wheat was seeded on field pea which had received 40 kg N ha⁻¹ the previous year. In rotation 3, spring wheat was seeded on field pea stubble which had received 0 kg N ha⁻¹.

Table 1.7. The effects of crop, rotation and N rate on β -Glucosidase enzyme activity (mg nitrophenol/kg soil/hr) in 2007 in the rhizosphere portion of the soil.

Crop	N (kg/ha)	Rotation 1 ^z	Rotation 2	Rotation 3
Field Pea	0	352	324	371
	20	431	333	-
	40	366	341	-
Spring wheat	80 (0)	446	-	-
	80 (20)	495	-	425 ^y
	80 (40)	468	-	429 ^x
^z Rotation 1=pea-wheat-wheat; Rotation 2=continuous field pea; Rotation 3= pea -wheat-wheat ^y Spring wheat on spring wheat stubble ^x Spring wheat on pea stubble				

Table 1.8. The effects of crop, rotation and N rate on β -Glucosidase enzyme activity (mg nitrophenol/kg soil/hr) in 2007 in the non-rhizosphere portion of the soil.

Crop	N (kg/ha)	Rotation 1 ^z	Rotation 2	Rotation 3
Field Pea	0	378	307	358
	20	400	376	-
	40	391	347	-
Spring wheat	80 (0)	469	-	-
	80 (20)	464	-	455
	80 (40)	442	-	440
^z Rotation 1=pea-wheat-wheat; Rotation 2=continuous field pea; Rotation 3= pea -wheat-wheat ^y Spring wheat on spring wheat stubble ^x Spring wheat on pea stubble				

Section 2: The effects of crop and crop rotation on soil bulk density, soil organic carbon and nitrogen.

Samples were collected in 2005 only. Refer to the 2005 results for more details.

Section 3: The effects of crop and crop rotation on nitrous oxide emissions.

The temporal distribution of soil-emitted N_2O from land seeded to annual crops on the Canadian prairies consists of very low “background” emissions interspersed with bursts of activity following snow melt in the spring and application of fertilizers or manures (Lemke et al. 1998). The bursts of activities are governed primarily by soil-water conditions and soil mineral N. For example, in 2005 emissions remained low after the site was seeded and fertilized on April 26, but increased markedly after the first substantial rainfall in mid-May (**Figure 1**). Further, emissions at that time were considerably higher from the fertilized (wheat) plots than from the unfertilized (pea) plots. During the balance of the season emissions were low and similar from the wheat and pea phases.

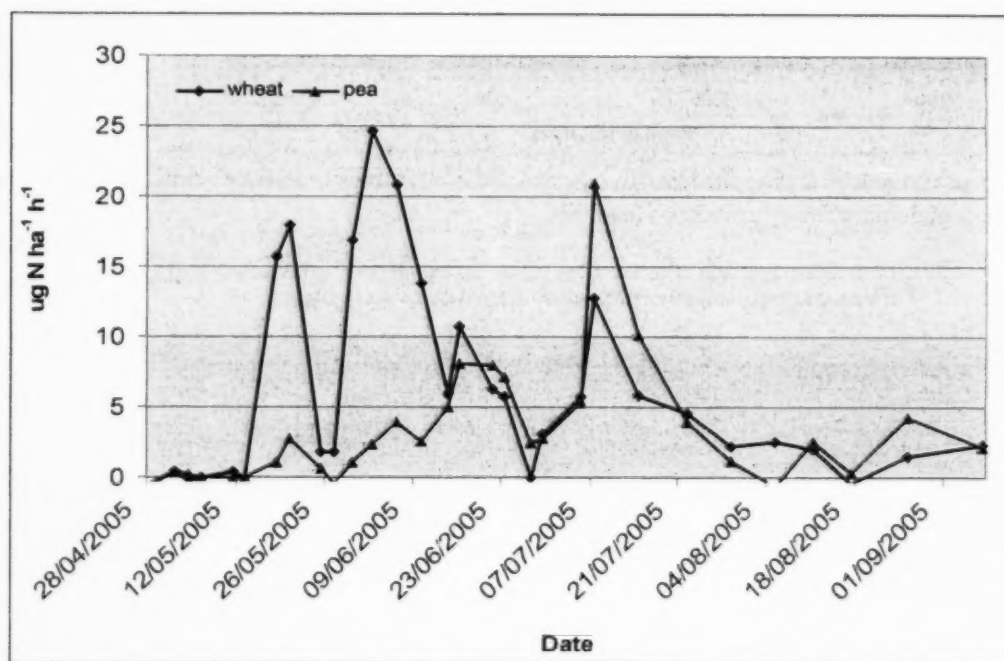


Figure 1. Mean N_2O emissions measured on each sampling date during the 2005 frost-free period on the Field Pea Management Study at Indian Head, SK.

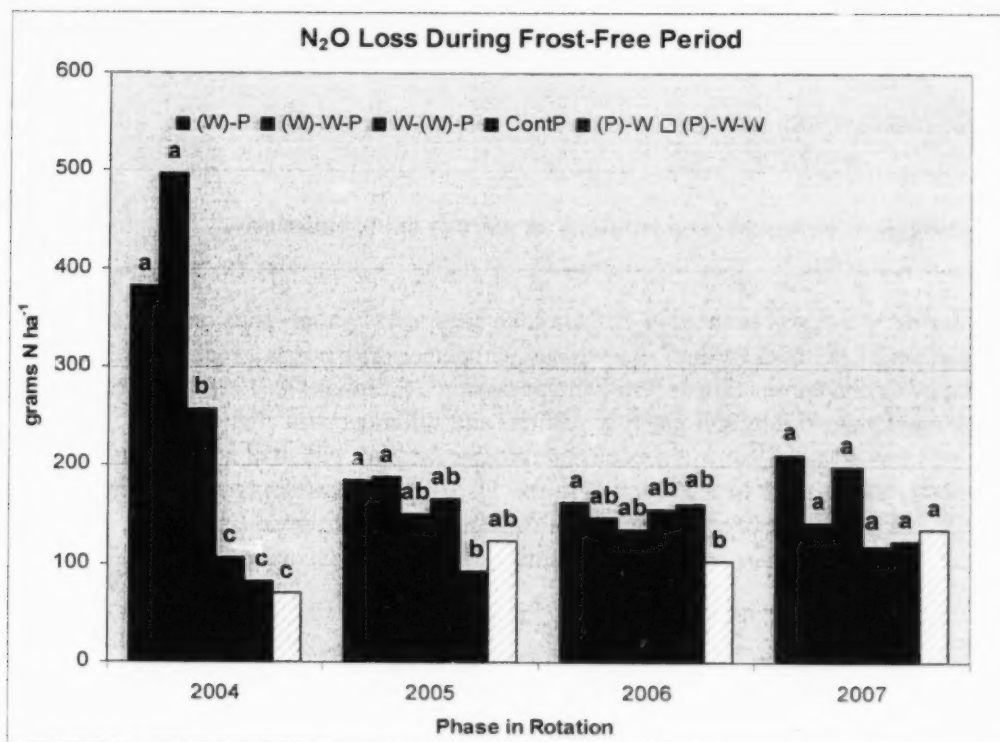


Figure 2. Nitrous oxide loss during the frost-free period (May-October) from the various phases of the Field Pea Management Study at Indian Head, SK.

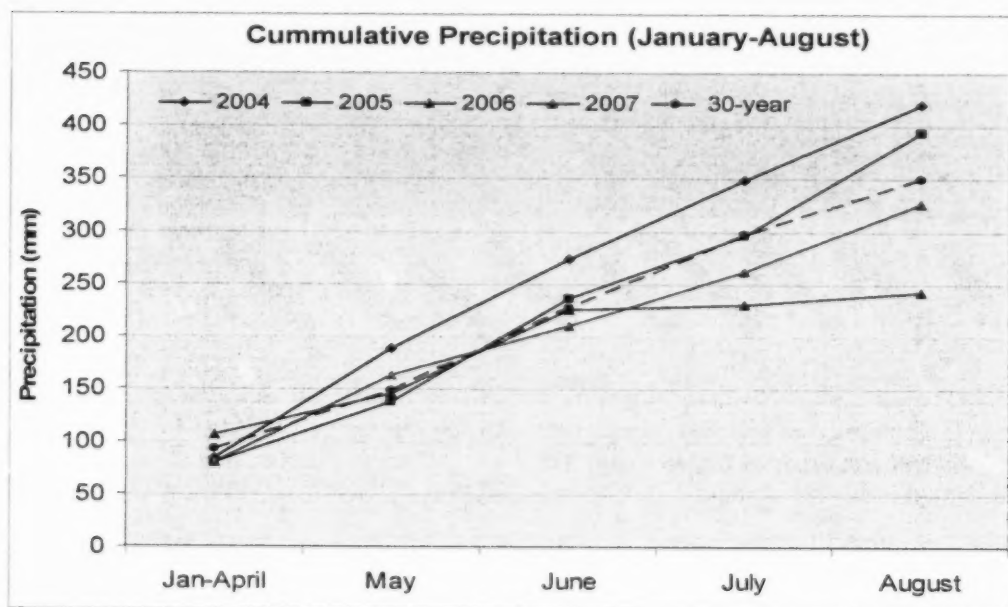


Figure 3. Cumulative monthly precipitation at Indian Head, SK. for 2004-2007 and the 30-year mean.

The fertilizer-induced emissions resulted in generally higher cumulative N_2O loss from plots sown to wheat compared to those sown to field pea (**Figure 2**). This difference was very clear during the frost-free period of 2004 but less so during the next three years. Notably, N_2O loss from plots sown to field pea varied little from year to year during the frost-free period. It appears that the yearly application of N-fertilizer to the wheat crops creates a potential for higher emissions compared to the field pea crops, but how strongly this potential is expressed depends on the soil-moisture regime. In 2004 when rainfall was higher than normal (**Figure 3**), the difference was significant, but under lower rainfall levels (e.g. 2006) the differences are minimal.

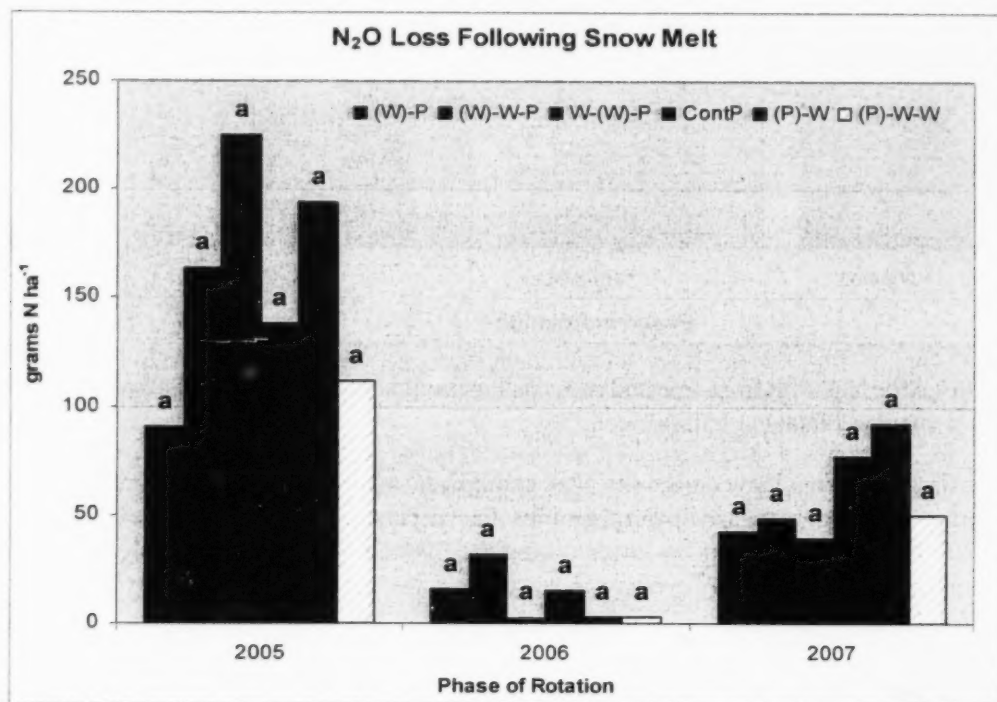


Figure 4. Nitrous oxide loss during the snow melt period (March-April) from various phases of the Field Pea Management Study at Indian Head, SK

Spatial and temporal variability of N_2O emissions during the spring thaw period is extremely variable. Although there were some substantial numerical differences between treatments there were no statistically significant differences in any of the three spring thaw periods measured in this study (**Figure 4**), most likely due to the extreme variability. N_2O loss during the 2005 spring thaw was considerably higher than during 2006 and 2007. This may, at least in part, be a reflection of the wetter soils due to higher than average rainfall in the previous summer.

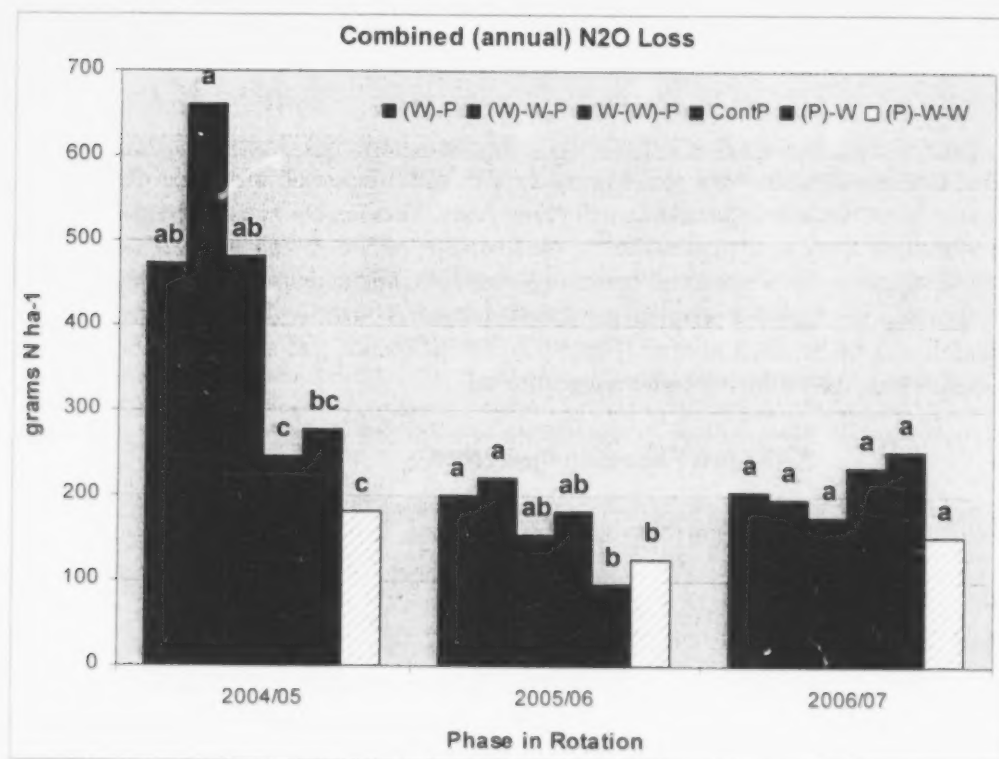


Figure 5. Nitrous oxide loss with frost-free and snow melt periods combined from various phases of the Field Pea Management Study at Indian Head, SK.

When the frost-free and spring thaw emissions were combined (one complete annual cycle), N₂O loss from the pulse phases were clearly lower than from the wheat phases for the 2004/2005 cycle (**Figure 5**). N₂O loss also tended to be lower during the 2005/2006 cycle, but no significant differences occurred for the 2006/2007 cycle.

Crop residues can stimulate N₂O production as they decompose and mineral N and oxidizable carbon becomes available to the microbes that produce N₂O. Residues with lower C:N ratios, such as those from field pea, are expected to stimulate N₂O emissions more than residues with higher C:N such as those from wheat. There was no apparent difference in N₂O emissions from pea grown on pea stubble [cont-P] to pea grown on wheat stubble [(P)-W and (P)-W-W] either for the frost-free or snow melt periods. However, N₂O loss from wheat grown on field pea stubble [(W)-P and (W)-W-P] was significantly higher than from wheat grown on wheat stubble [W-(W)-P] during the frost-free period of 2004, was numerically higher in 2005 and 2006, but there was no difference in 2007. Thus it appears that pea residues alone did not increase N₂O loss potential, but the combination of pea residue and fertilizer N application increased N₂O loss potential even more than fertilizer N applications alone, however this potential was only expressed when soil-water regimes were most favourable for N₂O production (higher than average rainfall in 2004).

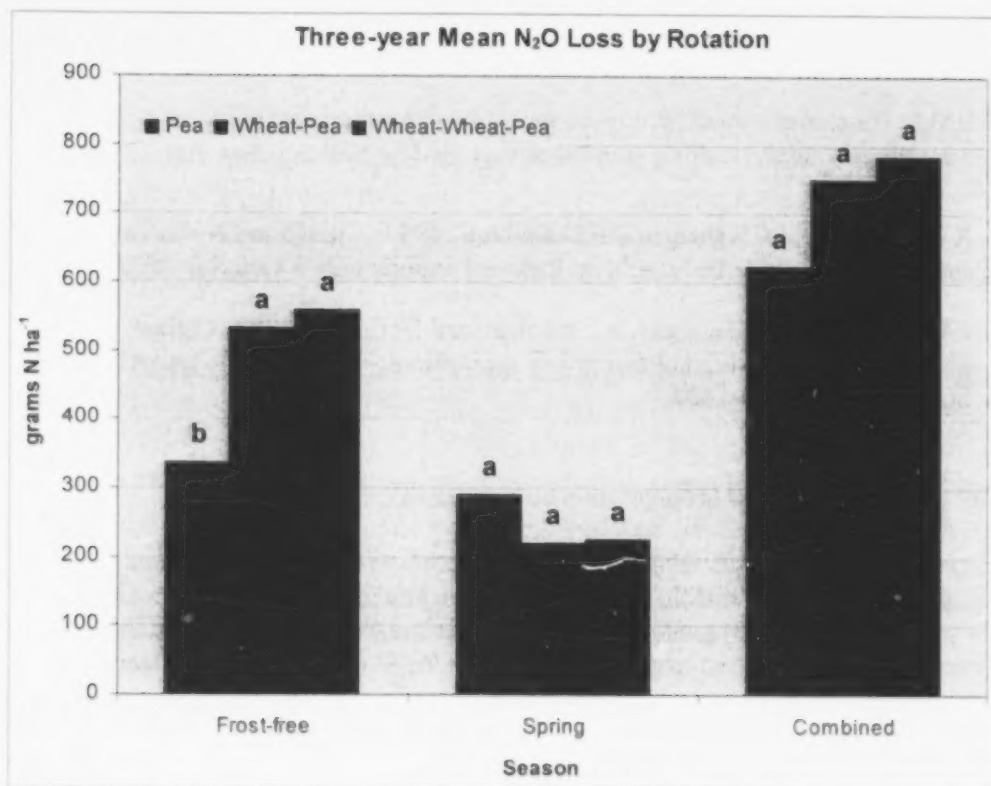


Figure 6. Three-year mean N₂O loss for different sampling periods on three rotations of the Field Pea Management Study at Indian Head, SK.

Figure 6 presents the three-year mean N₂O loss calculated on a rotational basis. N₂O loss was largely unaffected by rotation during the snow melt period, but increased with increasing frequency of fertilizer N application during the frost-free period. However the difference between the two year and three year rotations was not significant. Although the W-P rotation received fertilizer less often than on the W-W-P rotation, fertilizer N was applied to wheat grown on pea stubble more often than on the W-W-P rotation. Thus might why the difference between the F-W and the F-W-W was smaller than might be expected based on the frequency of fertilizer N application.

Conclusions

Pea phases tend to have lower emissions during the growing season than wheat phases. Fertilizer-induced N₂O emissions may be higher in the presence of pea residues, but this is more than offset by lower emissions during the field pea phase. At this site, applying fertilizer N increased the potential for N₂O loss, particularly when combined with pea residues, but that potential was only strongly expressed when soil-water regimes were favorable for N₂O production (higher than average rainfall). On average, over this three-year study increasing the frequency of field pea in rotation with spring wheat tended to decrease the loss of soil-emitted N₂O.

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Section 4: The effects of crop and crop rotation on nutrient cycling.

The largest numbers of effects with respect to N release was observed for ammonium-N after 14 days (Table 4.1). The pea stubble was releasing more ammonium than wheat stubble in Pea-W (Rot 1) and Pea-W-W (Rot3) rotations. However, the Cont-Pea (Rot 2) released the least amount of ammonium when compared to the Pea-W and Pea-W-W rotations. After 28 and 42 days, the Cont-Pea rotation was still releasing the least amount of ammonium-N.

With nitrate-N, differences were only apparent after 42 days (Table 4.1). This is to be expected given that the mineralization of N from organic matter starts with the release of N in the form of ammonium followed by the nitrification process which produces nitrate-N. The field pea phase in the Cont-Pea (Rot 2) was releasing more nitrogen than the pea phase in Pea-W-W (Rot 3). Overall, the Cont-Pea (Rot 2) released more nitrogen than Pea-W. There was no difference between Cont-Pea and Pea-W-W even though the release was higher for Cont-Pea.

With phosphorus, differences were observed between Pea-W (Rot 1) and Pea-W-W (Rot 3) on all three sampling dates (Table 4.2). The pea stubble in Rotation 1 (Pea-W) was releasing more P than the combination of wheat on wheat or wheat on pea stubble in Pea-W-W (Rot 3). However, close examination of the results shows that lower values were observed for wheat on pea stubble than wheat in wheat stubble in Pea-W-W (Rot 3).

With potassium, Cont-Pea (Rot 2) released the least amount of K on all three sampling dates (Table 4.2). The pea phase of Cont-Pea (Rot 2) also released less K than the pea phase of Pea-W (Rot 1) and Pea-W-W (Rot 3).

With sulfur, the only effect observed was with the use of starter N during the pea phase of Pea-W (Rot 1) and Cont-Pea (Rot 2) (Table 4.3). As starter N increased, the amount of sulfur released decreased and this was consistent for both rotations and on all three sampling dates.

Table 4.1. The effects of crop rotation and crop on the nutrient release of ammonium, nitrate and their combined sum after 14, 28 and 42 days. The values for 14, 28 and 42 days are cumulative.

Crop Rotation	Crop Rotation #	Crop	NH ₄ -N			NO ₃ -N			Total-N		
			14 days	28 days	42 days	14 days	28 days	42 days	14 days	28 days	42 days
			$\mu\text{g} / 10\text{cm}^2$								
Pea-W	1	Field Pea	4.4	14.9	20.7	318	467	883	322	483	904
Pea-W	1	Wheat	6.5	14.1	20.1	315	433	753	321	447	773
Cont.-Pea	2	Field Pea	2.9	10.4	14.8	326	485	1014	329	495	1029
Pea-W-W	3	Field Pea	8.2	16.2	22.3	249	340	690	257	356	712
Pea-W-W	3	Wheat	6.1	13	21.1	303	454	829	309	467	850
Pea-W-W	3	Wheat	5.7	19.1	27.1	296	416	843	302	435	870
		Contrast	p-values								
		Pea vs Wheat	0.011	ns	ns	ns	ns	ns	ns	ns	ns
		Pea: Starter N vs No N	ns	ns	ns	ns	ns	ns	ns	ns	ns
		Pea: Rot 1 vs Rot 2	ns	ns	ns	ns	ns	ns	ns	ns	ns
		Pea: Rot 2 vs Rot 3	0.001	ns	ns	ns	ns	0.033	ns	ns	0.0369
		Pea: Rot 1 vs Rot 3	0.015	ns	ns	ns	ns	ns	ns	ns	ns
		Wheat: Rot 1 vs Rot 3	ns	ns	ns	ns	ns	ns	ns	ns	ns
		Rot 3: Wheat vs Pea Stubble	ns	ns	ns	ns	ns	ns	ns	ns	ns
		Rot 1 vs Rot 2	0.009	ns	0.052	ns	ns	0.035	ns	ns	0.04
		Rot 1 vs Rot 3	ns	ns	ns	ns	ns	ns	ns	ns	ns
		Rot 2 vs Rot 3	0.0008	0.056	0.011	ns	ns	ns	ns	ns	ns

Table 4.2. The effects of crop rotation and crop on the nutrient release of phosphorus, sulfur and potassium after 14, 28 and 42 days. The values for 14, 28 and 42 days are cumulative.

Crop Rotation	Crop Rotation #	Crop	PO ₄ -P			SO ₄ -S			K		
			14 days	28 days	42 days	14 days	28 days	42 days	14 days	28 days	42 days
			$\mu\text{g} / 10\text{cm}^2$								
Pea-W	1	Field Pea	11.8	16.3	23.1	32.1	45.6	81.8	65	142	192
Pea-W	1	Wheat	16.5	20.3	26.5	34.6	44.4	69.9	66	148	210
Cont.-Pea	2	Field Pea	12.2	16.3	21.4	28.2	39.1	76.2	40	88	122
Pea-W-W	3	Field Pea	7.8	9.7	15.8	25.2	36.9	67.6	64	138	192
Pea-W-W	3	Wheat	6.1	8.8	13	43.6	58.4	86.9	56	131	187
Pea-W-W	3	Wheat	15.9	23.7	32.1	35.5	49.3	94.6	54	127	180
		Contrast	p-values								
		Pea vs Wheat	ns	ns	ns	ns	ns	ns	ns	0.05	0.016
		Pea: Starter N vs No N	ns	ns	ns	0.025	0.022	0.025	ns	ns	ns
		Pea: Rot 1 vs Rot 2	ns	ns	ns	ns	ns	ns	0.0006	0.001	0.002
		Pea: Rot 2 vs Rot 3	ns	ns	ns	ns	ns	ns	0.0145	0.024	0.022
		Pea: Rot 1 vs Rot 3	ns	ns	ns	ns	ns	ns	ns	ns	ns
		Wheat: Rot 1 vs Rot 3	0.007	0.016	0.025	ns	ns	ns	ns	ns	ns
		Rot 3: Wheat vs Pea Stubble	ns	ns	ns	ns	ns	ns	ns	ns	ns
		Rot 1 vs Rot 2	ns	ns	ns	ns	ns	ns	<0.0001	0.0001	<0.0001
		Rot 1 vs Rot 3	ns	ns	ns	ns	ns	ns	ns	ns	ns
		Rot 2 vs Rot 3	ns	ns	ns	ns	ns	ns	0.009	0.006	0.004

Table 4.3. The effects of starter N in field pea on the release of sulfur after 14, 28 and 42 days. The values for 14, 28 and 42 days are cumulative.

Rotation	Starter N kg N /ha	14 days	28 days	42 days
		$\mu\text{g} / 10\text{cm}^2$		
Pea-W (R1)	0	44.0	59.0	102.7
	20	32.6	44.6	73.0
	40	19.8	33.2	69.7
Cont.-Pea (R2)	0	40.6	53.2	101.2
	20	24.6	35.7	70.8
	40	19.3	28.4	56.6
Contrast		p-values		
0 vs 20&40		0.025	0.022	0.025
0 vs 20N		ns	ns	ns
0 vs 40N		0.016	0.016	0.028
20 vs 40		ns	ns	ns
Pea-R1 0 vs 20&40		ns	ns	ns
Pea-R1 0 vs 20		ns	ns	ns
Pea-R1 0 vs 40		ns	ns	ns
Pea-R1 20 vs 40		ns	ns	ns
Pea-R2 0 vs 20&40		ns	ns	ns
Pea-R2 0 vs 20		ns	ns	ns
Pea-R2 0 vs 40		ns	ns	ns
Pea-R2 20 vs 40		ns	ns	ns

